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Delay Actuator, Silicon Delay

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**FINAL REPORT**  
**A STUDY OF NOVEL DELAY MECHANISMS**

Long range delays are, at the present time, based on chemically and physico-chemically induced phase changes similar to the action of acid on metals or organic membranes or of solvents on high molecular organic substances. These delays are greatly dependent upon extreme temperatures, and, in fact, are extremely sensitive to all temperatures.

The primary objective of this project was to develop a delay which would compensate for the variations in delay time due to the influence of temperature. It was considered impractical to use the principles of the conventional delays, where dissolution of solids are involved; but rather to utilize the principles of expansion and contraction to compensate for temperature influence. The following lines of attack were considered:

1. Procure elastomeric materials of low physical changes over a wide temperature range (0°F or lower to elasticity at temperatures below 0°F, or produce suitably plasticized composition of low temperature variations).
2. Establish mechanisms of consistent movement at various constant temperatures to establish soundness of principle.
3. Combine temperature compensating mechanisms if necessary and possible with basic models under (2) above.
4. If successful, produce at least one workable short range and one long range model including some suitable activation at the end of the delay period.

-1-

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A feasibility investigation of a silicone material having cold-flow properties yielded results which showed promise. Before extensive investigations were conducted on this material, other methods of construction were evaluated.

The first model consisted of a rigid tube lined with a silicone rubber for 1-1/2 to 2 inches of its length through which a smooth body was forced. The second method of construction utilized a piston which forced silicone gum through an orifice. These methods of attack provided the necessary information for a tentative design.

Further investigations led to the purchase of rubber parts which would allow for a 2 inch plunger travel as opposed to the 1-1/2 inch travel in the first investigation. This provided information as to the time delay differential when the two lengths were subjected to identical pressures and climatic conditions.

Various tests were conducted using the silicone tube approach which proved unsatisfactory due to non-reproducible results. Further attempts were made to reproduce the action of a ball (or body) being forced through a silicone rubber tube having a smaller ID than the OD of the ball. Questions arose relative to the manufacturing tolerances of extruded tubing the effects of dimensional increases of the ball or body, as well as the spring constant or vice versa, and different geometric configurations of the ball or body.

During the investigation of the above questions, numerous variables were found to be present. Since no means of compensating for the deficiencies of the extruded tubing were feasible, the use of male and female molded

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parts seemed most practical. This approach reduced the variables considerably and gave complete control over configuration and dimensional aspects.

The first attempt to implement the new approach involved machining metal sleeves to serve as a restriction to the outward expansion or distortion of the rubber tube while the ball was being drawn through. To compensate for the spring loss, a taper was found to be necessary on the ID of the tubing.

Other variables such as the variation of plus or minus two points on the durometer of the molded parts and the normal shrinking tolerances existing in elastomeric molded items presented problems which were difficult to overcome.

Various types of silicone rubber stock having different durometer values were used in an effort to overcome the effects of the manufacturer's standard tolerances. This process of elimination expanded into a major task.

It appeared, at this time, due to the inability to reproduce the delay action within allowable limits, that an alternate approach should be considered. This involved the extrusion of a silicone gum through an orifice. This has the advantage of compensating for practically any variable.

Tests were conducted using three delay units filled with Dow Corning 400 Silicone Gum. Each unit featured an orifice of .023" x 2". These units were tested at ambient temperature (75°F). The linear travel of the plunger after an elapsed time of 84 hours was as follows:

Unit 1 - .075 inches

-3-

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Unit 2 - .078 inches

Unit 3 - .077 inches

The deviation between the units occurred during the first 16 hours and remained throughout the entire test (84 hours).

These same units were then placed in a test cabinet at -20°F for 96 hours. The mechanics of the units were undisturbed, however, the gauges were returned to 0°F after two hours in the test cabinet in order to allow for contraction of the silicone gum material. If this had not been done, the contraction would have resulted in a linear travel of the plunger which would have appeared to be a fast rate of extrusion. The contraction recorded on all three units was .0625 inches. The linear travel of the plungers after 96 hours was as follows:

Unit 1 - .1765 inches

Unit 2 - .1760 inches

Unit 3 - .1750 inches

Other tests were run to determine the delay characteristics of different sizes and configurations of orifices with other variables remaining constant. One of these tests included a delay unit with an orifice size of .052" x 2", subjected to -20°F for 138 hours with a plunger travel of 0.5085 inches. Another test was conducted with an orifice of .041" x 6" at room temperature (75°F) for 395 hours with a plunger travel of .480 inches. The same unit was then placed in a constant temperature of 120°F for 144 hours with a plunger travel of .191 inches. This is a variation of less than 9 per cent in rate of travel between the two temperatures.

-4-

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At this phase of the program, it was decided to investigate silicone gums of higher viscosity than those previously tested as they did not show promise for long time delays. A test unit was designed in which different molecular weight silicone gum resins could be evaluated.

A cylinder of acrylic plastic, 2 inches in length by 1/2 inch ID, was machined. One end of this cylinder had a shoulder on which the motivating compression spring was seated. A piston was machined undersized to allow for a silicone rubber coating which acted as an O-ring, thus assuring a good fit. Several "test units" were fabricated in order to study the behavior of these silicones while under pressure.

The results of preliminary tests showed that the units were reproducible. Different rates of linear travel were recorded at temperatures of -20°F, 70°F and 120°F. It was noted that between -20°F and +120°F, a difference of 140°F, an approximate five-fold change occurred in the rate of linear travel. This change was determined by placing the units on a test rig which measured the linear travel of the piston in the cylinder. Periodic readings were made to determine the rate of travel at different points along the 140°F temperature range. As a result of this test, it was found that a decrease in the rate of travel of the piston occurred. This decrease in rate of travel may be due to the following:

1. A drag caused by friction as the piston traveled through the cylinder.
2. A decrease in force upon expansion of the spring.

In order to determine the reasons for this drag, the cylinder walls of the test units were coated with silicone gum to simulate the lubricative

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properties of the gum resin. The units were then subjected to  $-20^{\circ}\text{F}$  and the rates of travel obtained. The results of this test illustrated that the "frictional drag" developed by contraction of the acrylonitrile cylinder against the piston amounted to only 2.5 per cent of the spring force of the original unit tested. Although this was a measurable quantity in this system, it is not considered to be of great importance. Upon completion of this test, an evaluation of the compression springs used was begun. The springs tested were compression type having a force of 16 pounds for a  $1/2$  inch length. When allowed to expand another  $1/2$  inch, a decrease resulted amounting to a 40 per cent loss in force.

Twelve springs were tested and all produced the same per cent decrease in applied force. A Rimac spring tester was utilized to further study the springs in respect to their change in force resulting from temperature changes.

A spring with known manufacturer's specifications was tested at room temperature and was found to conform with specifications. The tester was then subjected to a  $-20^{\circ}\text{F}$  temperature in order to check its operation. The tester was removed from the freezer. A spring of known force was immediately placed in the tester and the force obtained was the same as that at room temperature. From this test it was felt that the tester was not affected by the low temperature. A spring and the tester were then subjected to a temperature of  $-20^{\circ}\text{F}$ . The results of this test indicated that no difference in force existed, thus proving that the spring was not measurably affected by the low temperature.

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Several gum delay models employing three different designs for an adjustable orifice were fabricated. G.E. Silicone Gum Resin No. 81567 was chosen as the best material since it was less influenced by temperature and more viscous resulting in a longer time delay.

The first design, referred to as Model I, had various sized holes drilled through the end cap of the unit. These holes varied from .040" to .125" in diameter by 3/8" long, the thickness of the cap. These holes were so spaced that thumb screws could be placed in the holes. The number of hours delay each hole represented was scribed next to that respective hole. This feature was abandoned since it did not offer a sufficient number and range of time delays.

Model II employed the use of a cone of aluminum with a 0.120" hole, notched at one point on its base. The cap was then machined on the lathe to cut out a conical section which would correspond to the dimensions of the original cone. A number of holes were then drilled in the cap as in Model I. The cone was held in the cap by a thumb screw inserted through the cap. With the aid of a small spring situated between the head of the screw and the cap, a good pressure seal between the surfaces was obtained. The screw could then be used to select the delay time by turning the slotted cone to the appropriate orifice. This arrangement effected the selection of different time delays while only employing the use of one cap screw. This method proved unsatisfactory since a large time delay range could not be obtained due to the limited space available. This model was tested with no serious mechanical difficulties; however, the shortest delay which could be attained was approximately 14 hours.

-7-

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A larger orifice would easily solve this problem, however, the lack of area restricted attempts to do so.

Model III utilized the same cylinder and firing mechanism except for the top of the cylinder which featured a tapered portion which accommodated a corresponding needle attached to the cap. Screwing the cap in or out resulted in different flow rates. Evaluation tests indicated that the volume displacement change obtained per turn was such that a variance of thousandths, in the needle valve assembly, would cause considerable error in the time delay selected and that obtained. Further, it would increase the burden of manufacture and assembly.

The final design, Model IV, is very similar to the former designs with the exception of a ball bearing being used in place of the needle portion of the needle valve. This method proved to be satisfactory. Reproducibility is very good with little or no variation in the units tested. About 12 percent variance existed between tests conducted in three positions, i.e., vertical, horizontal, and inverted. Since this unit is a mechanical device, the position should have very little effect on the time delay.

Several means of temperature compensation were investigated which featured low manufacturing costs and simplicity of design. The properties of silicone gum resins as well as silicone fluids present many ideas as to possible applications for mechanical time delay systems. It is recommended that these materials be investigated further.

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